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High speed photography:
Its problems and limitations.

HIGH SPEED PHOTOGRAPHY:
ITS PROBLEMS AND LIMITATIONS

A Thesis

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by

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CHAPTER I

INTRODUCTION

THE PROBLEM AND ITS SCOPE

During the first half of the twentieth century, science and industry have literally produced miracles. Today one man can do the work of hundreds of the serfs of the Middle Ages. Today it is possible for one person, strategically located, to create infinitely more destruction with the wave of a finger than the armies of a whole continent could have done in a lifetime a few generations past.

With scientific and industrial advance there has long been the problem of analyzing and recording the unknown--the unknown being that unseen or undetected by the human eye. The microscope was developed to aid in the examination of the mysteries and motions of the minute. Similarly, today, the eye itself cannot detect or record the details of extremely fast motion, but aided by high-speed motion picture photography it can accomplish this analysis. Changes that take place in certain steps of processing, changes in the character of materials, which may occur almost instantaneously, changes in the medium through which an object or particle passes, disintegration of masses can now be studied visually through time magnification. High-speed motion picture photography can be defined simply as a means of

magnifying time.

I. THE PROBLEM

Statement of the problem. The purpose of this thesis is to analyze and discuss the techniques and procedures associated with high-speed motion picture photography, placing special emphasis on its inherent problems and limitations in order to aid the average motion picture photographer in obtaining a workable knowledge of high-speed methods and to obviate the necessity of time-consuming experimentation in the event he is requested to perform high-speed work.

Importance of the problem. High-speed motion picture photography is a relatively new field--its greatest advances having been made in the last two decades. World War II gave tremendous impetus to its applications, and its uses today in scientific and industrial research are increasing daily. In some military establishments such as the Aberdeen Proving Grounds and the U. S. Naval Guided Missiles Center, Point Mugu, it is commonplace. Despite this the writer feels that the average motion picture photographer, civilian and military (e.g., the cinema major at the University of Southern California, or the photographer in the majority of the military laboratories of the U. S. Navy) has at best a limited knowledge of the theory and practice of high-speed

photography.

It is believed that a study of the techniques and limitations of this phase of photography will be of value to the aforementioned average motion picture photographer in successfully pursuing his chosen career, because without a doubt he will sometime be called upon to participate in high-speed motion analysis.

II. REVIEW OF PREVIOUS RELATED STUDIES

One other thesis[1] has been written on this subject at the University of Southern California. Mr. Tudor's thesis is a comprehensive survey of the whole field of high-speed photography and contains descriptions of most of its associated equipment, including still equipment. The present thesis will, of necessity, cover some of the same phases of the field such as history and certain techniques. However, since high-speed photography is almost unlimited in scope, it is this writer's intent to delve more deeply into the details of its problems and eliminate theoretical and experimental high-speed photography, except as it may be related to future developments. In his thesis, Mr.

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[1] Ralph Neal Tudor, "An Investigation of the Techniques and Application of High-Speed Photography," (unpublished Master's thesis, University of Southern California, Los Angeles, 1950), 95 pp.

Tudor states, "The technique of high-speed photography should be simplified to the point where it is the tool of the average working photographer."[2] This writer will attempt to give a straightforward, simple explanation of the problems, slanting the discussion to the needs of the average working photographer, notably in the military, and emphasizing the practices, procedures, and equipment he expects to find of value in his own career as a naval officer associated with photographic work.

The Journals of the Society of Motion Picture Engineers have from time to time been devoted to discussions of high-speed photography. However, the problems are mentioned only in passing and to this writer's knowledge no previous attempt has been made to discuss the normal difficulties of high-speed photography in a comprehensive manner.

III. DEFINITIONS OF TERMS

Angle of Incidence. The angle formed by the line of a ray of light falling on a surface and a perpendicular arising from the point of incidence.

Frame. Each individual picture in a series of pictures on motion picture film.

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[2] Ibid., p. 94.

Frame frequency. The rate at which pictures are exposed.

High-speed motion picture photography. The taking of motion pictures at rates of 275 to 20,000 frames per second.

Picture frequency. Since some pictures in high-speed motion picture photography are not of standard size, the terminology "picture" is used in lieu of "frame" when discussing such non-standard pictures.

Reciprocity failure. Under extreme conditions the reciprocity law breaks down exhibiting what is known as reciprocity failure. This is an important consideration in high-speed photography where extremely high intensity light coupled with extremely short exposure time determines the film emulsion's reaction.

Reciprocity law. The product of the photochemical reaction is proportional to the total energy involved, that is, the product of intensity and time which are interchangeable.

Slow motion picture photography. The taking of motion pictures on normal intermittent operation type cameras at speeds higher than normal, usually 48, 64, or 128 frames per second.

Ultra high-speed motion picture photography. The taking of motion pictures at rates in excess of 500,000 frames per second.[3]

Very high-speed motion picture photography. The taking of motion pictures at rates of 20,000 to 500,000 frames per second.

In further discussion in this thesis, the term high-speed photography is construed to mean high-speed motion picture photography.

IV. METHOD OF PROCEDURE AND SOURCES OF DATA

For the purpose of this thesis, the writer is assuming that the average motion picture photographer has only a limited knowledge of high-speed techniques. This view has been supported by interviews with responsible persons in charge of military photography on the West Coast. To further support this contention, a survey was conducted in all the Fleet Air Photographic Laboratories in the Pacific, with the cooperation of the Commander, Utility Wing, Pacific Fleet, under whose cognizance these laboratories

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[3] Kenneth Shaftan, "A Survey of High-Speed Motion Picture Photography," *Journal of the Society of Motion Picture and Television Engineers*, 54:615, May, 1950.

operate.[4] One hundred and sixty-five photographers were asked if they understood the principle of using a rotating prism optical system to record pictures on continuously moving film, and if they had ever operated a high-speed camera. Ten understood the principle involved and eleven had operated such a camera.

Based on previous experience in military photography and on the conversations with civilian photographers, the writer assumed that the aforementioned average working photographer has an understandable knowledge of common photographic terms such as emulsion speed, optical path, millimeter measurements of width, aperture, focal plane, etc.

The bulk of the discussion consists of a correlation and interpretation of the currently available literature on the subject as available at the Library of Motion Picture Arts and Sciences, the Los Angeles Public Libraries, and the Library of the University of Southern California.

The biographical research is augmented by personal correspondence with manufacturers and designers and by personal interviews with engineers and photographers who utilize high-speed photography. Mr. William Christie,

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[4] A questionnaire was sent out as a part of Utility Wing Bulletin, Volume 20, dated May 21, 1951, in which the questions discussed were asked. The results were compiled July 13, 1951, and given to the writer in memorandum form.

physicist, and Mr. Louis Reeder, photographer at the Naval Ordnance Test Station, Pasadena, California, and Mr. Frank Crandall, of the California Institute of Technology have cooperated to the extent which security regulations will permit. The writer visited the Naval Guided Missiles Center, Point Magu, California, for the purpose of obtaining valuable background information on non-classified techniques.

V. ORGANIZATION OF THE REMAINDER OF THE THESIS

Chapter II will contain a brief history of high-speed photography. Chapter III will be devoted to a discussion of modern high-speed camera principles and design, emphasizing a standard camera now available and in wide use. Modifications for special purposes and experimental design will not be considered. Chapter IV will be concerned with the inherent problems and limitations of high-speed photography, namely, (1) Pre-analysis of the task, (2) Illumination, (3) Exposure, (4) Synchronization and Timing, (5) Arrangement of the subject to be photographed, (6) Film waste in acceleration, (7) Lack of an ultra high-speed film emulsion, (8) Projection and analysis problems, and (9) Miscellaneous considerations such as blur, focusing, etc. Chapter V will be a discussion of new techniques and trends. touching on a few of the latest and most important of the literally

thousands of methods promulgated since the inception of high-speed photography. Chapter VI will consist of a summary and conclusions.

CHAPTER II

THE HISTORY OF HIGH-SPEED PHOTOGRAPHY

Conceivably the history of motion pictures can be traced to the cave man era when man first drew crude multi-limbed animals on the walls of his dwellings to depict the movements of the animals so necessary to his existence.

High-speed motion picture photography is however primarily not an art of depiction but a science of motion analysis. The first serious attempt to analyze motion occurred in the 1870's as the result of a wager made between Leland Stanford and one Edweard Muybridge as to whether a galloping horse had one foot on the ground at all times, or whether there was a certain stage in the gallop in which all four feet left the ground simultaneously.

Mr. Muybridge set up a series of still cameras in a line and placed wires across the path of the horses. The wires tripped the shutters one after the other which recorded the progression of the animal's movement across a given field. Viewing them by means of a Zoetrope, a slotted circular drum with a serious of pictures mounted on the interior periphery, the party who bet that the four feet were off the ground simultaneously won the bet. This experiment was the first of many that Muybridge conducted

on locomotion.[1]

At the turn of the century, 1900, a Frenchman, E. J. Marey, started the first multiple image photography by placing a fixed slot at the lens of a camera and then rotating a disc with a number of slots in front of the lens. A black background was used and by opening the shutter just before the action started, and illuminating only the subject a multiple image picture of the subject's motion was produced. This method is still in common use today.[2]

At approximately the same time, Thomas A. Edison developed his Kinetoscope, which showed photographs in motion for the Chicago World's Fair of 1893. His peep show cost a nickel and involved forty feet of film which lasted for all of thirty seconds. Another Frenchman, Lumiere, seized upon Edison's idea and developed a camera and projector (called a cinematograph) for mass audience viewing which utilized a strip of film seventeen meters long. After 1900, the motion picture grew very rapidly all over the world. This early motion picture history is shrouded in a

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[1] Francis X. Dercum, "A Study of Some Normal and Abnormal Movements Photographed by Muybridge," <u>Animal Locomotion, the Method and the Result</u> (Philadelphia: J. B. Lippincott Company, 1888), pp. 103-133.

[2] John H. Waddell, "High Speed Photography," (unpublished paper, Copyright, 1949, by Bell Telephone Laboratories, Inc.), p. 1.

have that is a combination of fact and fancy, with the latter predominating in most popular works.[3]

The development of still photography led to almost phenomenally short exposures and following this lead, camera manufacturers set about developing high-speed motion picture cameras, and the modern cameras were born. High-speed photography reached its apex of accomplishment in 1946 with the photography of the atom bomb tests. More of its development will be discussed in later chapters as the history relates to specific problems encountered in the construction of the cameras.

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[3] William H. Offenhauser, 16-mm Sound Motion Pictures (New York: Interscience Publishers, Inc., 1949), p. 3.

CHAPTER III

MODERN HIGH-SPEED PRINCIPLES AND DESIGN

Shortly after the invention of the motion picture camera and the projector, the natural speed of subjects on the screen was altered by changing the camera speed, the projector speed, or both. Action was accelerated to achieve slapstick effects in comedies, while for motion analysis, such as in sports events, it was slowed down.

Gradually the value of the slow motion picture for analytical purposes became more evident, and attempts were made to increase the taking rate until speeds in excess of two hundred frames per second were attained. This resulted in the slowing up of action by more than ten times when the film was projected at sixteen frames a second. Although this was adequate for analysis of most physical action, it became increasingly apparent that much higher taking speeds were necessary for analyzing fast mechanical movements. The conventional intermittent motion picture camera is limited mechanically to speeds not in excess of two hundred and fifty frames per second.[1] Above this speed they mutilate the film beyond recognition or in some cases the camera itself may literally fall apart. The conventional

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[1] Maynard L. Sandell, "What is High Speed Photography?" Journal of the Society of Motion Picture Engineers, 52:5, March, 1949.

intermittent mechanism had to be supplanted, resulting in the high-speed motion picture camera as we know it today.

Motion picture cameras capable of speeds greater than two hundred and fifty frames a second generally employ a rotating prism or mirror (to be described later), a series of rotating lenses, or a stroboscopic light source instead of the usual shutter and intermittent mechanisms. In the latter case, the camera is equipped with a commutator to synchronize the flashing light with the film movement and the camera is operated in a dark or semi-darkened room. Such cameras cannot be used for photographing self-luminous subjects. Cameras employing the rotating prism principle usually bracket the range from two hundred and fifty to ten thousand frames a second. Speeds in excess of ten thousand frames a second fall in the classification of ultra high-speed photography and are usually attained in what are known as strip cameras.[2]

The rotating prism motion picture cameras are the most commonly used high-speed cameras today because of their portability.[3]

Also, the rotating prism camera is adequate for most

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[2] _Ibid._, p. 6.

[3] "High-speed Motion Picture Photography," _Journal of the Society of Motion Picture Engineers_, 53:442, November, 1949.

analytical purposes. Maynard L. Sandell, of the Eastman Kodak Company, reports that rarely have they found an instance in industry where the three thousand frame top speed of their camera was not adequate.[4]

For these reasons, we will confine the discussion in this chapter to the principle of the rotating prism and a description of a typical camera of this type.

Simply stated, in the rotating prism type camera the image from the lens is projected through a rotating prism which is so designed that its rotation causes the image to move in the same direction as the film is moving and at the same speed. Thus during exposure the image and the film are actually stationary with respect to each other, and exposure is accomplished with no blur or image displacement. The principle is illustrated schematically in Figure 1.

The image gathered by the lens is refracted by the prism upward to meet the incoming frame and as the frame advances downward, the image follows, thereby permitting continued exposure throughout the period that the film passes the aperture.

In this type of camera the glass prism must have a number of pairs of parallel faces. In the cameras

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[4] Maynard L. Sandell, personal letter dated March 16, 1951.

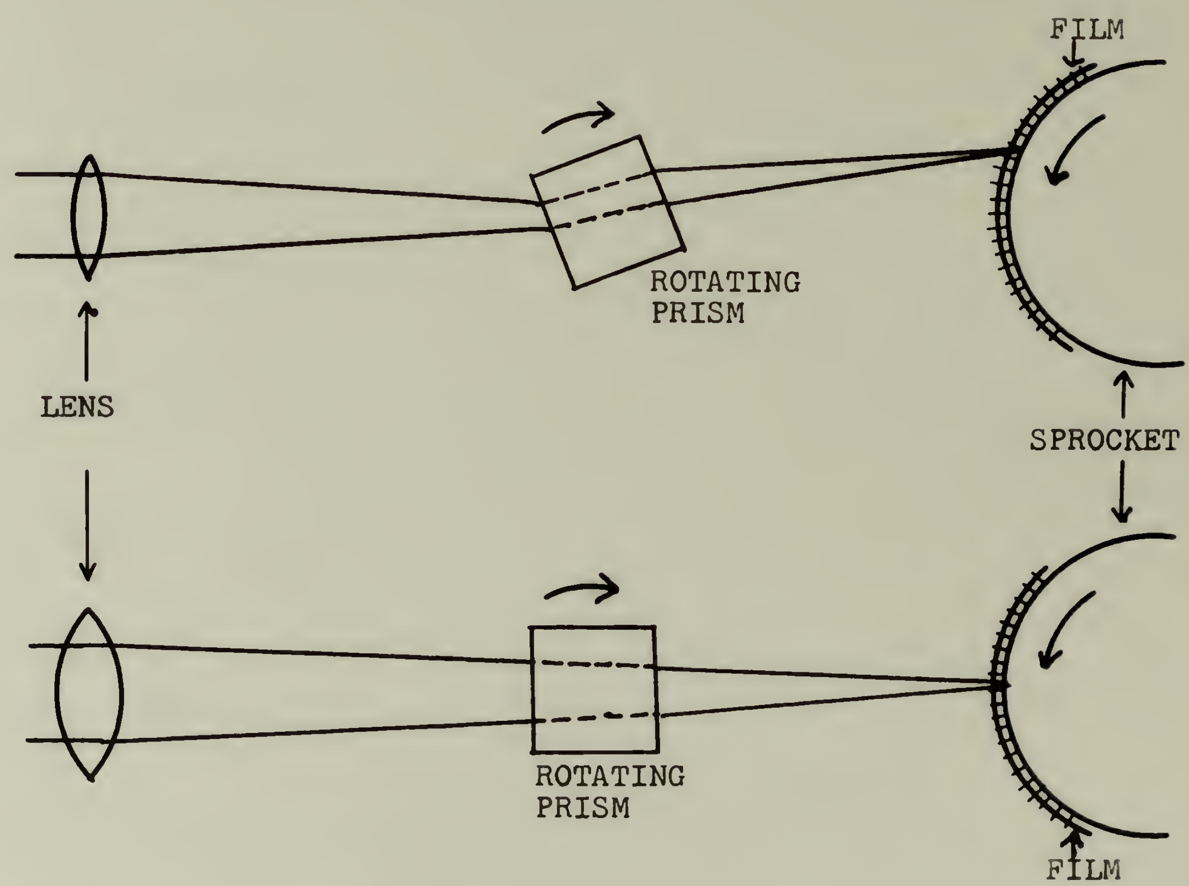

FIGURE 1

OPTICAL SYSTEM OF ROTATING PRISM CAMERA

commercially available today, the number varies from two to eight depending upon the size of the aperture and the method of prism calculation. The thickness of the glass depends upon the index of refraction, the picture frame height, the angle of rotation in which the picture is laid down and the peripheral speed of the image, which as previously mentioned, must be equal to the linear speed of the film.[5]

For any given set of conditions, many problems are presented in the design of rotating prism cameras.

Super-precision bearings are a necessity on the prism shaft. If the shaft is eccentric the pictures will be noticeably jumpy and on projection difficulty will be encountered in determining whether the unsteadiness is caused by the subject being photographed or by the camera itself. The speed of rotation varies in inverse proportion to the number of parallel prism sides so in general it may be said that those cameras employing the square or octagonal prism produce greater picture clarity and more reliable operation.

The rotating prism acts as a shutter as well as an image compensating device: The exposure time is dependent upon the maximum angle of incidence of the rays of light

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[5] John H. Waddell, "Design of Rotating Prisms for High-Speed Cameras," Journal of the Society of Motion Picture Engineers, 53:497, November, 1949.

exposing one frame. As the prism rotates, the angle of incidence and thus the image speed varies on the focal plane. Also the optical path is lengthened because of the increased thickness of the prism. These obstacles are overcome by proper aperture design before and behind the prism which in effect determines the maximum angle of incidence and by proper sprocket design which lengthens and decreases the optical path by means of its curvature, minimum extension occurring on the optical axis of the camera through the center of the prism and terminating on the most forward portion of the sprocket.

The use of prism glasses of high index of refraction and low dispersion with minimum thickness and minimum angle of incidence, in conjunction with suitably designed components such as lenses, sprockets, bearings, and so forth produce results with rotating prism cameras which will approximate the quality obtained with an intermittent-type motion picture camera.[6]

The most widely used high-speed cameras today are the Eastman Kodak Model III and the Wollensak Optical Company's Fastax. They are almost universally employed because of their portability, simplicity, dependability, and

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[6] *Ibid.*, p. 501.

adaptability to most applications of high-speed photographic analysis.

Despite some design differences both manufacturers offer cameras which fundamentally operate on the same principles and find the same application in industry.

Because the Wollensak Fastax is available in 8, 16, and 35mm, as compared to only 16mm in the Eastman III model; because it is more widely used;[7] and because the military photographers will in all likelihood encounter it first when introduced to high-speed photography, we will discuss its design and operating principles as an illustration of a modern high-speed rotating prism type camera.

The Fastax camera is manufactured in three models, each using a different film size, namely, 8mm, 16mm, and 35mm. The 8 and 16mm cameras take pictures of standard frame size; the 35mm records pictures of one-half standard frame height or approximately 3/8 inches high by 1 inch wide--the variation being due to the design of the rotating prism--the 16 and 35mm models utilizing a four sided prism and the 8mm using an octagonal prism. The minimum and

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[7] Kenneth Shaftan, "A Survey of High-Speed Motion Picture Photography," Journal of the Society of Motion Picture and Television Engineers, 54:605, May, 1950. Of 273 camera users asked, 134 used Fastax cameras as compared to 74 for Eastmans.

maximum exposure rates vary from one hundred and fifty pictures per second to fourteen thousand pictures per second depending upon the camera models. Operating speeds and projection ratios are shown in Table A, following.

TABLE A[8]

Camera Exposure Rate (pps)	Ratio of Motion to Projection (at 16 pps)	Camera Speed Limits
150	9.4:1	16mm (minimum)
300	18.75:1	8mm (minimum)
500	31.25:1	35mm (minimum)
5,000	312.5:1	35mm (maximum)
7,000	437.5:1	16mm (maximum)
14,000	875.0:1	8mm (maximum)

The construction of the camera is extremely simple. (See Figure 2.) The film runs from the supply spool, driven by the feed spindle, beneath the hold down rollers which maintain even film feeding and over the film sprocket. The forward portion of the film sprocket maintains the film in the proper position for exposure by running in synchronism with the rotating prism by mechanical linkage. From the sprocket the film passes the timing unit which places an image of a flashing timing light (commonly called "timing pips") on the edge of the film for analysis purposes, the frequency of the flash being determined by the alternating

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8 Fastax Instruction Bulletin (Rochester, New York: Wollensak Optical Company, 1950), p. 8.

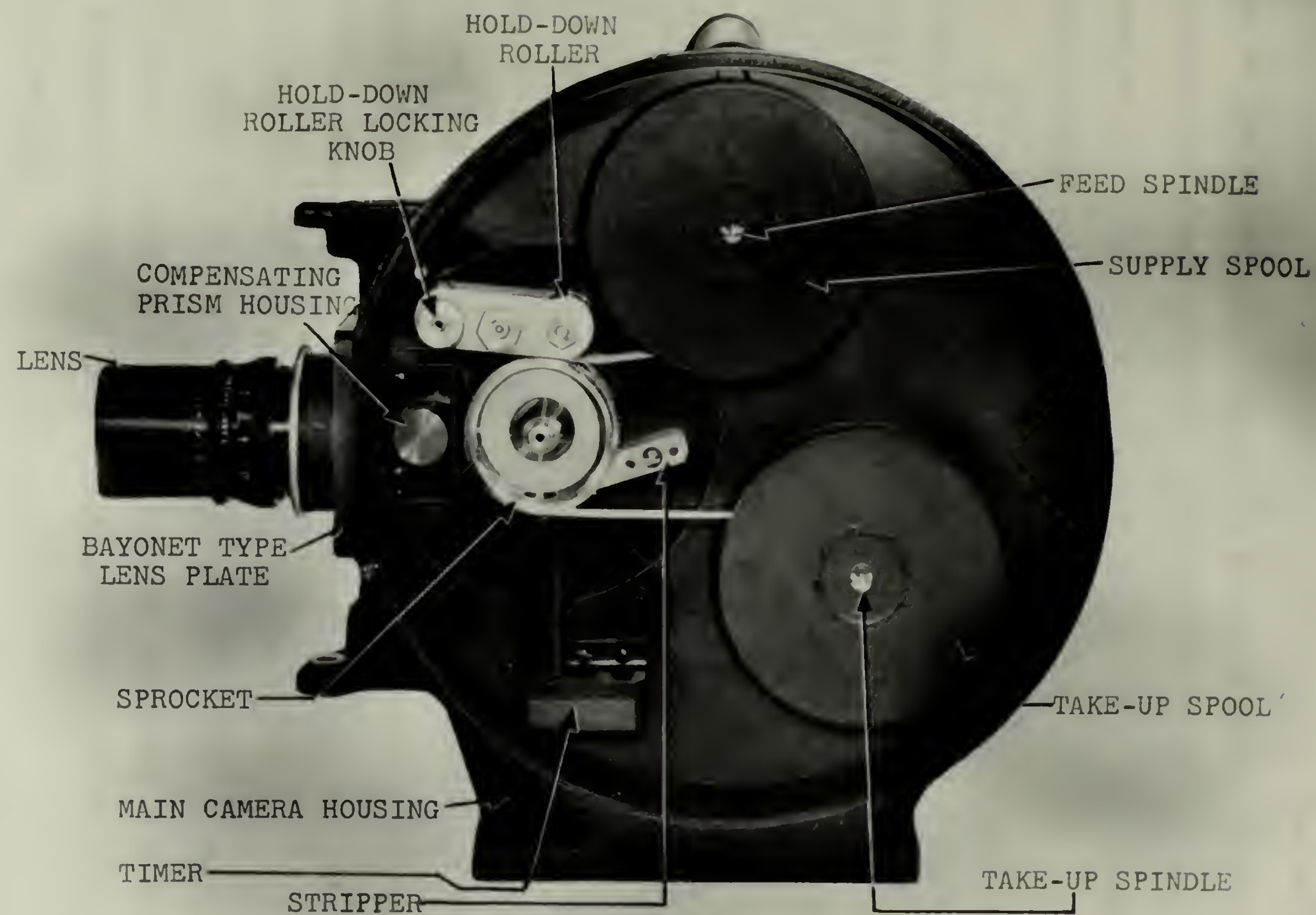

FIGURE 2

INTERIOR FASTAX CAMERA

current being used. From the timer the film proceeds to the take-up spool. The film stripper, mounted at the take-up side of the drive sprocket, is a precautionary device to prevent film jamming around the sprocket in the event of breakage, a situation which at high speeds could cause severe mechanical damage to the camera.

The main housing door, containing a film guard which controls the path of the film, swings over the components shown in Figure 2 and provides a light-tight camera.

Externally mounted on the camera housing are the lens and protective cap, the drive and the take-up motors and the carrying handle (Figure 3.)

To improve acceleration characteristics both film drive and take-up are actuated by separate electric motors. Speed of operation or rate of exposure is regulated by controlling the voltage level of the power supplied to the motors. Both motors are of the universal type and can be operated under normal conditions on either direct or alternating current (60 cycles/second or lower).

Film specially spooled on aluminum spools must be used in the Fastax Camera. Failure to do this will upset the dynamic balance of the components and result in damage to the camera.

The film has special rectangular perforations rather than the standard Bell and Howell negative perforations.

FIGURE 3

EXTERIOR FASTAX CAMERA

because of the finer tolerance required at high speeds. Nitrate films must <u>never</u> be used because fire may result from the friction due to the whipping of the film at the end of the run.

Complete operating instructions are furnished by the manufacturer with each camera, and so they will not be discussed as a portion of this chapter. Operating characteristics will be explained subsequently to the extent that they impose limitations on the application of high-speed motion picture photography.

CHAPTER IV

PROBLEMS AND LIMITATIONS OF HIGH-SPEED MOTION PICTURE PHOTOGRAPHY

Perhaps no phase of motion picture photography requires more careful planning and preparation than does high-speed photography. It is absolutely necessary to analyze the problem, determine as exactly as possible the results required, and eliminate as many unfavorable photographic factors as possible before proceeding with the actual photography.

It is the purpose of this chapter to discuss some of the more common problems to be considered before using the high-speed camera, regardless of the type. Given proper thought, these factors no longer are problems, but become incidental considerations that may work to the advantage as well as the disadvantage of the cameraman.

To illustrate the importance of determining exactly what is to be photographed; what the most important action is; and what motion or phase of motion is most desired in the final analysis, it is interesting to note the request that preceded the Bikini test of the atom bomb.

> From the Manhattan District to the Air Forces came this request, "Get us on film," said the scientists, "the first one-tenth of a second after bomb burst. And, if possible, get it so that it can be broken down for analysis to less than one ten-thousandth of a second." For good measure they had gone the Manhattan District

one better. The delivered film was so marked that it could be measured in terms of 500-millionths of a second.[1]

The first requirement of successful high-speed photography is to know exactly what phase of action you wish to record on the film.

Illumination. Discussion of the problems of high-speed motion picture photography are equally applicable to any make or model of camera, except, perhaps, those using the stroboscopic light for exposure. Operating at high speeds, the actual exposure time of any one picture will vary from 1/15,000 of a second to 1/1,500 of a second depending upon the operating speed and the type of camera. With these short intervals of exposure, adequate illumination becomes a serious problem.

The problem of illumination is best discussed in two phases--outdoor lighting and indoor.

An extensive study was made at Bell Telephone Laboratories of how best to take high-speed pictures out of doors. It was found that in the Southwest portion of the United States in the desert, the sunlight has its highest actinic[2]

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[1] G. Warrenton, "Greatest Photographic Organization in History Shot Bikini Blast," American Cinematographer, 27: 383, October, 1946.

[2] That property of radiant energy by which chemical

value in April.

Under ideal conditions, John Waddell states that it is possible to photograph out-of-doors at a picture frequency of 5,000 pictures per second, using Super XX film.[3]

The weather, whether cloudy or clear, and the clarity of the air are the controlling factors of lighting out-of-doors.

Well known to astronomers is the apparent out of focus picture which is obtained by a disturbance or by foreign particles in the atmosphere. Under controlled conditions in a building especially designed for such work, astronomers at Mount Wilson observatory in California were able to work successfully on about one night in ten in reproducing photographs of the moon through a lens system 270 feet long because of foreign matter in the atmosphere.[4]

The well-known heat mirage seen on the surface of hot roadways by motorists causes similar distortion as do the exhaust stacks on aircraft in flight if the field of view of

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changes are produced in light sensitive materials, such as film emulsions.

[3] John H. Waddell, "High Speed Motion Picture Photography," (unpublished paper. Copyright 1949 by Bell Telephone Laboratories, Inc.), p. 41.

[4] William Christie, Physicist, Naval Ordnance Test Station, Pasadena, California. Personal interview, April, 1951.

the aerial camera crosses the exhaust trail. It is important to recognize whether such distortion or blur is caused by atmospheric conditions or by excessive subject motion.

In the desert, the distortion due to heat waves, can be almost entirely eliminated by increasing the height of the camera above the ground to about thirty feet. Plotting the picture resolution against camera height gives an accurate method of determining the proper camera height under most field conditions.[5]

Full color pictures can be made by using an exposure factor of 64 times the exposure allowed for black and white on Super XX film.[6]

The normal film speed ratio between type A Kodachrome and Super XX is 1:12 but the reciprocity failure is greater on the Kodachrome so that an abnormal film speed compensation must be used. This reciprocity effect will be discussed more fully under the topic Exposure.

In cases when normal sunlight does not provide sufficient illumination, the Naval Ordnance Test Station, Pasadena, California, has discovered that a standard Navy searchlight played upon the subject in effect doubles the

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[5] Loc. cit.

[6] Waddell, op. cit., p. 58.

exposure from a distance of approximately 150 feet. Using this method they have obtained excellent results in photographing the effect of ricochet on missiles encountering the water at high speed.[7]

Indoors, unless the subject is self-luminous, high-speed photography must be accomplished by the use of extremely intense artificial lighting. The sub-committee on illuminants for high-speed photography of the Society of Motion Picture Engineers have established the following requirements for an illuminant.

1. It should cover an area to be photographed of 4x4 inches.

2. The minimum distance from the source to the area is 18 inches.

3. The variation in the illumination from the center of the area to the corners should not exceed 2 to 1.

4. It should produce a minimum value of illumination at the center of the target of 50,000 foot-candles although 100,000 foot-candles may be required.

5. A color temperature[8] of the source of approximately 3500 degrees Kelvin is desirable.

6. Lamps would be operated at full power for approximately 10-second periods.

Other desirable features include compactness, sufficient strength to provide illumination with only two

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[7] Christie, loc. cit.

[8] The color quality or degree or whiteness of the light, measured by the Kelvin scale of temperature.

lengths, and the use of tungsten cleaning powder to prevent blackening.[9]

The most widely used and most satisfactory photographic lamp is the incandescent type. Their advantages are numerous--they can be operated from storage batteries or from almost any lighting circuit without regulating equipment. They operate with equal efficiency on either alternating or direct current, the variation of light on alternating current being less than five per cent for lamps above 100 Watts on 60 cycle circuits. The light source is easily concentrated by reflectors, either external or integral with the lamp itself. They light quickly, reaching their peak of efficiency in less than a second and extinguish equally as rapidly. Finally, their spectral-energy distribution is such that satisfactory color rendition is possible when using the proper films. Among their disadvantages are their quick response to changes in applied voltage and the heat generated while in use.

The General Electric Company, bearing in mind the specifications listed previously, have developed a special lamp for close-up-high-speed photography, designated by the manufacturer's model number 750-R. It is designed to

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[9] R. E. Farnham, "Lamps for High-Speed Photography," Journal of the Society of Motion Picture Engineers, 52:35, March, 1949.

operate approximately eighteen inches away from the subject and has an intensity of 75,000 candle power within five degrees of the beam axis at that distance. Two of these lamps provide sufficient illumination on a 4" by 4" subject for the exposure of 5,000 black and white pictures per second at f5.6. When four are used on the same subject, 5,000 pictures per second may be taken at f2.[10]

Electric-discharge lamps are seldom used although their color rendition is excellent and they radiate little heat. The output follows the variation of an alternating current so that when used in motion picture work it produces a series of alternating under- and over-exposed pictures, depending upon the synchronization between the lamp and camera. Also, it is extremely difficult to obtain high levels of illumination, the source brightness of mercury lamps ranging from 175 to 6,000 candles per square inch, as compared to 20,000 to 24,000 for incandescent lamps. Finally, they require from one to four seconds to come up to full brightness.

Ordinary fluorescent lamps are not applicable for high-speed photography since they are of relatively low brightness, it being impossible to obtain more than about

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[10] Fastax Instruction Bulletin (Rochester, New York: Wollensak Optical Company, 1950), p. 10.

500 foot-candles on a surface, irrespective of the number of lamps employed or their position.

Flashtubes and photoflash lamps have been successfully applied to special circumstances in high-speed photography. The routine use of such sources of illumination is not considered practical, however, at the present time because of the time consumed in replacing the bulbs.

Exposure. Closely coupled with illumination is the problem of exposure. The correct combination of light (illumination) passing through a regulating valve or aperture (f stop) and falling on the correct film for a certain critical time will produce the correct exposure. Generally speaking, exposure depends upon the lighting, the speed of the film, the picture frequency or camera speed, the size of the diaphragm opening, and the color of the subject.

Exposure values in standard photography are at present determined by one of the following three methods.

1. By the individual's personal experience with his own particular photographic equipment operating under light conditions familiar to him.

2. Through reference to exposure calculator charts commonly furnished by the film manufacturers, the use of which are dependent entirely upon the user's ability to classify typical lighting conditions.

3. Through the use of photoelectric or extinction-

type exposure meters.[11]

For all practical purposes in photographic work at lower frequencies exposures can be calculated on the basis that the effect on the film is proportional to the product of the exposure time and the light intensity, regardless of their respective values. However, in high-speed photography where exposure time is extremely short and illumination is very high, this assumption will lead to underexposure.

For example, if proper exposure is obtained at a lens opening of f5.6 and a frequency of 1000 frames per second, it does not necessarily follow that the exposure at f4 and 2000 frames will be adequate, even though about the same amount of light reaches the film in both cases.

This apparent failure of the film to record an image at higher speeds is known as reciprocity effect and must be considered by every cameraman engaged in high-speed motion picture photography. No exact data can be given for the exposure increase necessary to compensate for reciprocity effect because it varies from one emulsion type to another.

For this reason, it is important to keep an accurate record of exposure data to use in determining future

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[11] E. T. Higgins, "Exposure Meter for High-Speed Photography," Journal of the Society of Motion Picture Engineers, 53:5?5, November, 1949.

exposures. A record sheet, suggested by the Eastman Kodak Company is shown. (See Figure 4.)

The frames exposed during acceleration of the camera are an excellent guide to correct exposure. For example, if the pictures obtained at maximum speed are underexposed, some of the frames exposed during acceleration will probably be exposed correctly and the exposure correction can be made accordingly.

These methods fall under the category of personal experience as mentioned previously.

Realizing that under high-intensity lighting conditions the human eye is incapable of any reasonable accuracy and that each lighting set-up poses a new problem, the Weston Electrical Instrument Corporation has developed a meter for determining exposure at high speeds.

The light meter consists of a light-sensitive cell mounted in a small paddle equipped with an extension cable to permit more comfortable reading of the instrument away from the intense illumination area. The cell connects to an electrical instrument providing a basic range of 3,000 foot-candles which will be found adequate for most outdoor work, except under rare conditions of very bright sunlight. Two carefully calibrated slip-on diffusion multipliers are supplied to extent the range to 30,000 and 60,000 foot-

Subject________________________________ Date____________
Photographed by_____________________________________
at____

Camera set-up
Film-plane to subject distance_________ Lens_______ f stop__
Speed settings____________________ Max. Speed____________
Voltage (at camera)____________ Type of current___________

Lighting set-up

Type	Watts	Volts	Unexp Lamp Life	Type of Re-flector	Lamp to Subject Distance	Angle from Lens-subject axis

Reflectors, type and position____________________________
Line Voltage used____________ Type of current____________
Type of light meter____________________________________
Method of measuring____________________________________

Film
Development____
Roll identification____________________________________

Subject
Color____
Speed of movement and direction in relation to camera______

Subject's preparation__________________________________

Other comments, sketches, etc.___________________________

FIGURE 4

HIGH-SPEED PHOTOGRAPHIC RECORD SHEET

candles.[12]

Supplied with each meter is an exposure calculator which gives appropriate camera settings for various types of cameras and films under specific light conditions. The exposure tables are based upon the actual use of the meter with the cameras under test conditions. Thus basically, even by using the meter, the exposure is determined in the broad sense by past experience. The meter is designated by the manufacturers model number 757.

Synchronization and timing. Since the Fastax cameras, when running at full speed, exhausts the film in about 1.4 seconds, and the Eastman camera only a little longer, it is necessary to accurately synchronize the action to be photographed with the camera.

It was determined that it was possible to double the speed of the Fastax camera by applying 280 volts directly to the camera motors. However, when starting the camera at this speed, the film would strip at the sprocket holes. Therefore, a 70-millisecond delay circuit was interposed so that the camera could start at 130 volts, run at 4,000 feet per second for 70 milliseconds and by jumping the voltage to 280 volts bring the camera to the full speed of 7,500 frames

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[12] Ibid., pp. 547-548.

per second.

With the advent of these high speeds it became increasingly more difficult for the operator to synchronize camera and action being photographed because one hundred feet of film travels through the camera in eight-tenths of a second.

The Industrial Timer Corporation of Newark, New Jersey developed an automatic control unit (commonly called the "goose" because of the peculiar jumping action in increasing the voltage) which by this principle actually doubles the picture taking speed of the camera, controls the film speed from low to high, automatically controls the camera in synchronism with an event to be photographed, allows for remote-control operation of the event and the camera, and prevents tearing of film as the camera is started. It is simple in operation, extremely accurate, and completely portable.[13]

The photography of smaller and more complex subjects has led to the development of complicated electronic relays which control with extreme accuracy the synchronization mentioned above. Ordinarily, their assembly and operation

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[13] L. L. Neidenberg, "Control Unit for Operation of High-Speed Cameras," Journal of the Society of Motion Picture Engineers, 52:107, March, 1949.

is not a task for the cameraman but for the research engineer and scientist. For this reason, it is mentioned only as a sidelight to the problem of synchronization.

The early application of high-speed photography was mainly one of visual study of the film when the action was slowed down during projection. From a very generous estimate on the part of the cameraman as to how fast he may have been cranking his camera or how accurately he may have read the camera tachometer, the methods have advanced to the point of millisecond accuracy. Today, high-speed photography is inseparable from timing and analysis, so that every high-speed camera is almost invariably equipped with some means of putting a time record on the film simultaneously with photographing some specific phenomenon.

The earliest attempts to establish a time base consisted of photographing a chronometer simultaneously with the subject. The timepiece had to be in the field of view of the camera and thus seriously limited the type of subject matter. Later, the clock was incorporated in the camera itself and its image placed on the film by means of an auxiliary optical system.

Modern high-speed cameras incorporate a timing light (Figure 2, Chapter III) which is satisfactory for most analysis. The timing device in the Fastax camera consists

of a neon glow lamp enclosed in a small housing mounted under the drive sprocket in the camera housing. The lamp is energized by alternating current surges from an accurately controlled source and is connected through a receptacle on the outside of the housing. The light emitted is focused on the edge of the film by a small lens in the top of the housing. Lamp operation results in timing marks appearing along one edge of the developed film outside of the picture area. The length of the mark will vary with the speed of the film and the frequency of the light. The frequency can be maintained at any rate by means of appropriate oscillators; ordinarily, however, the lamp is connected to the normal 60 cycle supply. In either case, the time between exposures can readily be obtained by dividing the time interval between the start of each flash by the number of intervening frames. For example, with the timing light connected to a 60 cycle line, and thirty-three pictures between two timing marks, dividing the number of pictures by the time interval (.00833 or 120 flashes per second) gives the camera speed, 4000 pictures per second. The time between exposures is .00833 divided by 33, or an interval of .00025 seconds.[14]

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[14] Fastax Instruction Bulletin, op. cit., pp. 17-18.

Another simple time base is described by Eyles in the Journal of Scientific Instruments.[15] The time base consists of an electrically maintained 1000 cycle per second tuning fork carrying slit apertures in overlapping plates at the ends of the prongs. Light from a small tungsten filament lamp is concentrated onto the slits by means of an optical system, and an image of them is focused on the film (between the perforations). As the fork vibrates the slits are displaced relatively one to the other, and the light beam is interrupted to produce a time base divided into one thousandth second intervals in the form of a series of dashes photographed along the edge of the film.

The flashing lamp, the oscillator, and the tuning fork are the most common time indicating devices in use in high-speed photography today. It is well to reemphasize the importance of the time base--without it mathematical analysis would be almost an impossibility.

Arrangement of the subject. The human eye and brain are incapable of assimilating several simultaneous actions on the screen. Therefore, in taking high-speed pictures the primary rule of photographic composition is to make the

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[15] E. D. Eyles, "Simple Time Base for a High Speed Cine Camera," Journal of Scientific Instruments, 20:114-115, July, 1943.

picture as simple as possible by confining the subject under study to one of its component actions rather than to the subject as a whole.[16]

For example, if photographing the operation of a gun-sighting computer, rather than attempting to make a high-speed picture of the whole unit at once, it is better to photograph individually various springs, cams, levers, and similar devices. Greater magnification is obtained when the single subject is photographed and it is easier to analyze both visually and mathematically.

Many times the subject will be unable to withstand the heat emitted by intense illumination indoors. Water jackets are expensive to construct and are not readily portable. The simplest and easiest method of combating this problem is to interpose a piece of heat-absorbing glass between the lights and the subject being careful to pick up no reflections and to correct the exposure to compensate for the slight loss of light. Such glass goes by the trade name of Aklo and is available from both Corning and Libbey-Owens-Ford Glass Companies.

Often times the subject can be improved by judiciously painting it to provide contrast to its surroundings. In

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[16] "High Speed Photography," Journal of the Society of Motion Picture Engineers, 53:445, November, 1949.

the case of color photography, the background should be complementary. Air currents can be made visible by the addition of smoke; water currents by interspersing small, buoyant, colored objects or dyes.

Sometimes it is apparently impossible to attain such isolation of the subject, a situation taxing the resourcefulness of the photographer. This problem in particular requires pre-study to determine the most desirable conditions for photography. An example of resourcefulness was given by Jones and Eyles in a recent review of British methods of photography.[17]

In connection with the photography of the rolling of red-hot steel bars, in order to show the surface texture as the bars emerged from the rollers, it was found that this could not be observed in high-speed films taken in a straightforward manner, because the intrinsic brightness of the red-hot surface of the bar prevented any rendering of texture by external lighting. It was realized, however, that hot metal does not emit any appreciable quantity of ultra-violet radiation and thus the bars were successfully photographed by means of ultraviolet lighting using a Wratten Filter No. 18A

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[17] G. A. Jones and E. D. Eyles, "Recent British Equipment and Technique for High-Speed Cinematography," Journal of the Society of Motion Picture Engineers, 53:513, November, 1949.

over the camera lens to cut out all visible light. Ordinary high-speed panchromatic film is sufficiently sensitive in the region just below the visible to enable a good record to be made, and also the ordinary glass lenses are sufficiently transparent to the near ultraviolet. By using this method special materials and the use of quartz lenses were avoided.

Film waste. Closely coupled with the previous problem of synchronization is the loss of film during the acceleration of the camera. Almost eighty per cent of a one hundred foot roll of film is expended while bringing the camera up to full speed. Some of this waste has been eliminated by the development of the "goose", but the inherent problem still remains. Larger spools of film are impractical because of the high rotational speed of the spool itself. Also adding to the expenditure of film, is the fact that once started the camera must never be stopped until all the film has passed through the camera. Stopping it before this will result in serious damage to both camera and film. Thus in most instances a magazine of larger capacity is not required.

For completely indoor photography with artificial illumination, the California Institute of Technology has devised an ingenious system to utilize completely the one hundred feet in a standard roll of film. It consists of an

endless film arrangement, the opposite ends of the roll being spliced together in a loop. At the proper speed the lighting system is turned on to provide exposure; previous to this the room is completely dark. The only drawbacks are the additional synchronization required to extinguish the lights before double exposures occur on a portion of the film and the possibility that an extremely important action may occur at the precise instant that the splice is passing the aperture thus ruining the most important exposure.[18]

<u>Lack of ultra-high-speed film emulsions</u>. Today's film emulsions are eminently satisfactory for most normal motion picture photography in the so-called low operating ranges of from sixteen to one hundred and forty frames per second. If a sufficiently fast film were developed, high-speed photography could conceivably become as commonplace as the use of the box camera. The photographic resolving power of an optical system is conventionally expressed in lines per millimeter, this numerical value being arrived at by viewing a set of parallel lines (in which the width of the lines is equal to the width of the spaces between them) and counting the just-distinguishable lines. In addition to the

[18] Frank Crandell, Physicist, California Institute of Technology, Pasadena, California, personal interview, April, 1951.

resolving power of the optical system, the resolving power of the film emulsion in recording the lines must also be considered. The resolving power of the Fastax camera is in the neighborhood of thirty lines per millimeter, whereas the resolving power of a particular film is usually much higher, ranging from forty to one hundred and twenty lines per millimeter. From the foregoing it seems reasonable to assume that present films are adequate, but from a user's standpoint, the resolving power ratings currently provided by film manufacturers are little more than a qualitative guide, as the specific test conditions under which a published value is obtained are rarely, if ever, explicitly stated in published technical data. The data furnished by the manufacturer are a theoretical maximum attained under conditions optimum for the emulsion. In high-speed motion picture photography, the photographic resolving power is reduced by low contrast in the final photograph, which is accentuated by underexposure, and further degraded by imperfect compensation for film movement and by movement of the subject itself during exposure.

Serious illumination problems would not exist were the films available today of sufficient speed, coupled with reasonably fine grain and good resolving power.

The emulsion speed can be increased somewhat by the

process of latensification.

The process is simply that of exposing a previously exposed negative to a weak source of light for several minutes. The intensity of the post-fogging light is adjusted so that a slight amount of fog is produced in the unexposed areas. The original exposure affects silver grains in the emulsion that do not develop under normal conditions. These sub-threshold grains, however, are affected more strongly by the energy from the post-fogging light than those which were previously unexposed. By the time that the latter are exposed to a developable level, those which had some previous exposure respond as though three to four fold more image exposures had been given them originally.

The equipment for latensification can take a variety of forms, but can be visualized as a dry box arrangement wherein a negative can be exposed to a weak source of light for a number of minutes as it passes through on its way to the developing machine.[19]

In practice in high-speed photography post-exposure can increase the emulsion speed by one f-stop or two times. Some increase in graininess is apparent but is not objectionable since in ultra-high-speed photography, the elimination of grain with present-day films is almost an impossibility.

Projection and analysis problems. Making a high-speed photographic study is only one part of the problem. The finished film must be interpreted by the user, usually by projection, and frequently by study of frame by frame enlargements or by frame by frame examination of the film

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[19] Jackson J. Rose, American Cinematographer Handbook and Reference Guide (Los Angeles: Southland Press, 1950), pp. 189-190.

itself. To an engineer trained in motion analysis, a slowed-down film is easily distinguishable from a normal film of the same machine running slowly. The layman, on the other hand, has little conception of such subtle differences, as vibration effect, etc., and it is necessary to provide a frame of reference. This can usually be accomplished by a careful analogy, usually taken from nature. For example, if studying a power press which operates with a frequency of seventy strokes per second, the reference object could be a humming bird whose wings beat seventy times a second.

For complete comprehension, several hundred feet of film showing the normal operation of the subject and the analogy is useful.[20]

Any good make of projector is adequate for screening the film but it should be capable of forward and reverse motion and still-picture projection. A footage counter is also very useful.

For frame by frame analysis an editing viewer can be used to advantage. Perhaps the most useful equipment for such quantitative analysis is the film reader of the type put out by the Recordak Company. These readers, originally

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[20] Henry M. Lester, "High-Speed and Time Lapse Photography in Industry and Research," Journal of the Society of Motion Picture Engineers, 52:76-77, March, 1949.

designed for reading microfilm, attain a magnification of from twenty-four to thirty-five diameters and can be used either for frame by frame analysis or three other motor driven rates of film advance. Either way the viewing plate is constantly held in critical focus and the machine is designed for maximum ease of operation, ideal placement of the screen, flexibility, and convenience of use.[21]

<u>Miscellaneous considerations</u>. The major problems of high-speed motion picture photography have been discussed. Coupled with these are minor problems that are merely a matter of familiarity with the tools of photography which, when not considered, probably will lead to unsatisfactory results.

The lens compensation necessary for rotating prism cameras has already been mentioned. It is important to remember that lenses designed for ordinary motion picture cameras cannot be used with the rotating prism type due to the normal short rear focus. This problem can be eliminated for high-speed cameras by building an extension tube on the front of the regular lens and focusing it on the image of a wide angle lens mounted at the front of the tube. This is,

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[21] Wade S. Nivison, "Methods of Analyzing High-Speed Photographs," <u>Journal of the Society of Motion Picture Engineers</u>, 52:56, March, 1949.

in effect, taking a picture of a picture.[22]

High-speed cameras must always be focused through the lens. The Fastax cameras manufactured by the Western Electric Company were found to be out of focus at infinity because the lenses were adjusted by a man whose eyes were optically different from normal eyes.[23]

If the image is blurred or fuzzy it is not always the result of failure to stop the subject's motion during photographing. If it is due to inherent camera design or to atmospheric conditions, no increase in camera taking speed will eliminate the trouble. By converting the subject's speed into feet per second, then finding the distance it travels (in feet) per exposure, and dividing this by the distance the camera is located from the action, and converting the result to millimeters it can be determined how far the image will move on the emulsion during exposure. If this falls within the resolving power of the film, blur can normally be expected to be absent. If blurring should occur, however, it can be assumed that it is not the result of insufficient camera speed. For example, if an object is

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[22] W. Herring, Lt., U.S.N., Photographic Officer, Naval Guided Missiles Test Center, Point Magu, California, personal interview, May, 1951.

[23] Fastax News Letter (Rochester, New York: Wollensak Optical Company, January, 1951), p. 1.

moving 1000 feet per second at a distance of 1000 feet from the camera, which is operating at 1000 frames per second or having an exposure of $\frac{1}{5000}$ of a second, the subject will move during exposure $\frac{1}{5000}$ x $\frac{1000}{}$ or 1/5 of a foot. The image on the focal plane will move $\frac{1}{5}$ x $\frac{1}{1000}$ (distance away) or $\frac{1}{5000}$ feet, or .06 millimeters, which falls within the resolving power of the film (normally thirty lines/mm in practice). This is an approximation which forms a guide of what to expect before actually taking the pictures.

Vibration of the camera during operation can cause a very disturbing result on the final picture. When projected the image appears to float upon the screen with a peculiar ghostlike movement. The solution of such a problem is obvious--make certain that the camera is securely mounted. In the rare cases where the camera is hand-held the advantage of rapid field coverage must outweigh the disadvantage of the floating image.

The problems encountered in high-speed motion picture photography have been presented with the realization that each individual set-up will undoubtedly present its own peculiar difficulty. However, these factors must be considered in every photographic task.

CHAPTER V

NEW TECHNIQUES AND TRENDS

In general there are two methods of stopping the motion of the image with respect to the film in high-speed photography. The first of these methods, the use of a compensating prism, has been described. The second method is the use of stroboscopic light to illuminate the subject, the flashes of light being of such short duration that the film does not move appreciably during the exposure. A third method has recently been developed to link the flashing lamp with the rotating prism type camera. In this case the incandescent lamp is replaced by a flashing lamp and incorporated in the high-speed camera is a triggering device which allows the lamp to be fired when the picture frame is on a line with the optical axis of the complete system.

The advantages of this system are numerous. The camera can then be used for an even greater variety of work--outdoors using it as is, and for indoor work requiring short exposure time using the same camera. Results have indicated that much better definition is obtained in the rotating prism camera when used in conjunction with strobe lighting, which is of particular advantage where frame by frame inspection of the film is to be made for purposes of analysis by measurement. Motion is stopped absolutely and little blur results. A further advantage is gained in those

cases where the subject is liable to damage by heat because of the relative coolness of stroboscopic light.[1]

Heretofore, in all high-speed photography, instantaneous time covered one complete frame, the continuity of instantaneous frames forming the time axis. A new method of obtaining high-speed pictures has been developed whereby instantaneous time covers multiple small portions of a single frame, the total area of these small portions being sufficient to provide detail and the single frame being large enough to permit unmagnified observation. Such a method is called grid-framing.

The framing grid is a focal plane shutter with a series of parallel slits placed at regular intervals across it. This shutter, therefore, is only required to move the distance between two successive slits to expose the entire film. To understand how this grid records successive frames, consider a series of optically clear slits .0005 inches wide, cut at .015 inch intervals across a 4x4 inch optically opaque plate. If this grid is held in a fixed position on a 4x5 inch photographic plate, a single exposure made through it will consist of a set of parallel lines which occupy only

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[1] Kenneth J. Germeshausen, "New High-Speed Stroboscope for High-Speed Motion Pictures," <u>Journal of the Society of Motion Picture Engineers</u>, 52:24-34, March, 1949.

1/30th of the total picture area with an over-all dimension of 4x4 inches. By moving the grid across the film perpendicularly to the slits for a distance of .0005 inches and exposing a second still picture in this new position, a second series of lines lying alongside of the first set and again occupying only 1/30th of the total picture area will be produced. Thirty such single pictures will result from only .015 inches movement of the grid and will expose the entire film area. To the casual observer the resulting picture will be an indistinguishable jumble. However, by proper positioning of the grid, anyone of the thirty exposures can be studied separately. This type of grid framing has been used for years in animated greeting cards and photographic advertisements.

If the photographic object is moving, and if the grid is moved at a uniform rate across the film for a distance of .015 inches, the resulting picture can be viewed through a grid as thirty separate exposures, one at a time, or by viewing through the grid moving at any uniform speed, flickerless motion pictures will be observed.

At the Aberdeen Proving Ground Laboratory, they have successfully combined a stationary framing grid with a rotating mirror to obtain framing rates in excess of 100,000,000 frames per second.

<u>The rotating mirror-grid combination</u>. The optimum slit width for the multi-slit focal plane shutter appears to be of the order of .0001 inches. A shutter with .0001 inch slits is required to move 10,000 inches/second to produce 100,000,000 frames per second. It is impractical to accelerate to, maintain, and decelerate from such high velocities with a linearly moving shutter. A rotating focal plane shutter on the other hand has the double disadvantage of requiring tapered radial slits and the combination of a large diameter and high rotational velocity. A method for moving the image of the shutter across the film plane by reflection from a rotating mirror was obviously a simple solution. (Figure 5.)

A first lens is used to image the event on the grid. The combined event-grid is then focused on a second lens, whose image, after reflection from the rotating mirror falls on the film plane as shown. The photograph formed by the reflected grid differs from that formed through a grid moving across the film plane in that the latter records a varying time, varying space image while the former, by virtue of the subject's fixed position with respect to the grid, records a fixed space, varying time record which is particularly suited to the studies of detonation and shock waves.

Of course the continuous motion of the image across

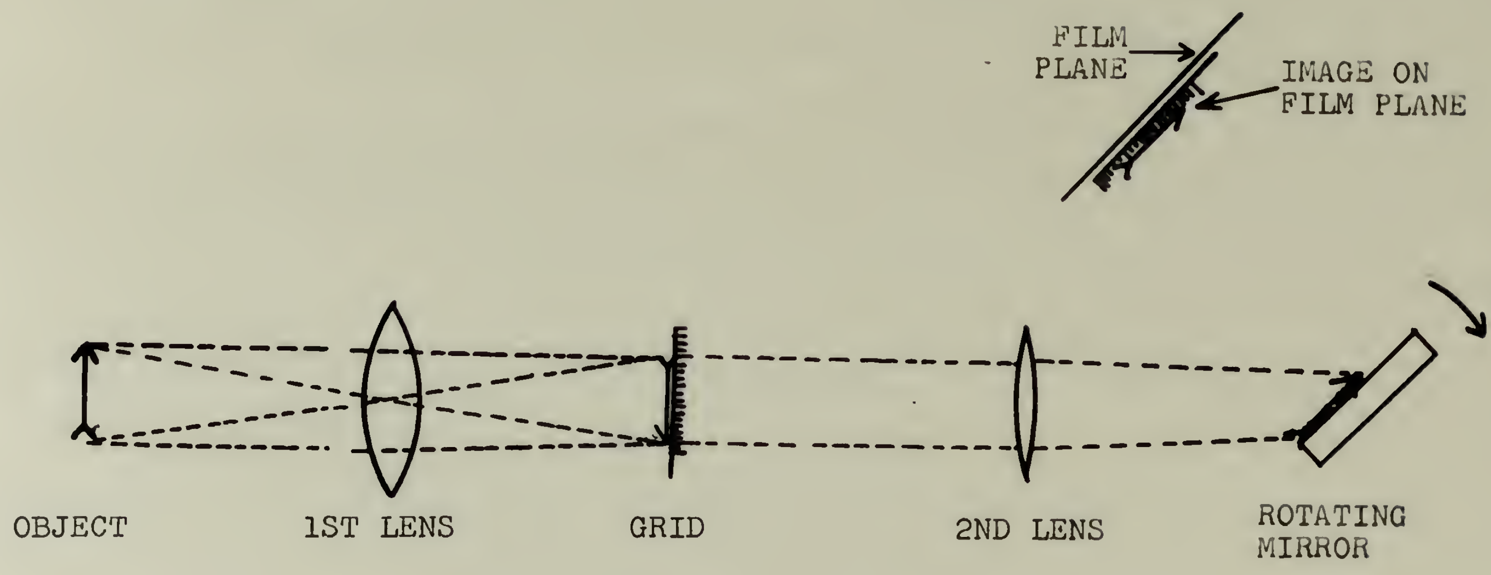

FIGURE 5

OPTICAL SYSTEM GRID-ROTATING MIRROR CAMERA

the film does not form a well-defined frame line as in other high-speed motion picture cameras. Since the exposure time of an increment of film is equal to the time it takes a slit to move its own width the reciprocal of this time is taken as the framing rate. The mirror rotation rate can be varied up to five hundred revolutions per second. At full speed with a .0001 inch slit the framing rate is 1.25×10^9 or 1,250,000,000 frames per second. The total exposure time is extremely short. With thirty frames taken at 100,000,000 per second the total exposure time before the film is exhausted is 3×10^{-7} or 3/10,000,000ths of a second.[2]

Compared to the Fastax camera's total exposure time of 8/10 of a second at maximum speed, this is an extreme disadvantage and it can be used to photograph only very short actions which must be timed electronically and perfectly. If the Sultanoff rotating-mirror grid camera were capable of recording a full second of action at 100,000,000 frames per second, and if the film were normally projected at 16 frames per second, it would require over seventy-two days of constant projection to view the film.

It has been mentioned that a conventional

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[2] M. Sultanoff, "A 100,000,000 Frame Per Second Camera," Review of Scientific Instruments, 21:653-654, July, 1950.

intermittent type motion picture camera cannot operate without damage in excess of 250 frames per second. The rotating prism cameras theoretically can operate at rates of from about 400 frames per second upward to seven thousand. In 35mm work the rotating prism type's minimum operating speed is 500 frames per second; but from a resolution standpoint it is impractical to operate it at below 1000 frames per second. The most commonly used 35mm intermittent type camera is the Mitchell which operates at a practical picture taking frequency of 140 frames per second. There has long been a great need for a camera to bridge the gap between these two types of cameras.

The Wollensak Optical Company is now working on an answer to the problem. They are designing, and hope soon to have available, a new super-Fastax camera which will have an operating speed with a minimum of about 100 frames per second and a maximum of approximately 2500 frames per second. In addition, it is being designed to eliminate other faults found in the previous Fastax; the frame size will be the standard full-size 35mm, not half height as previously; the resolution is estimated to be approximately eighty lines per millimeter through improved sprocket design; the capacity of the camera will be 400 feet allowing a greatly increased maximum running time. In addition, its construction will be

such as to withstand gravitational accelerations of 100 to 150 g, allowing it to be used on devices which previously could not carry cameras without danger of ruining them because of excessive acceleration forces.[3]

This will, without a doubt, be the most important single recent development for the average motion picture photographer engaged in high-speed work.

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[3] John H. Waddell, Wollensak Optical Company, personal letter, dated June 13, 1951.

CHAPTER VI

SUMMARY AND CONCLUSIONS

I. SUMMARY

With any type of high-speed camera it is essential to pre-determine the various factors that affect the final picture quality, and so adjust these factors that optimum results will be attained. From the inception of motion pictures as a research tool, and perhaps far into the future, each exposure presents its own problem. Research engineers and manufacturers are laboring constantly to control these factors until at the present time photography is taking its place along with the microscope, the cathode-ray tube, and various other instruments as an instrument for recording and measuring transient phenomena.

II. CONCLUSIONS

The applications of high-speed photography are almost unlimited. It can save time on break-down testing by pointing out trouble spots in advance, and by providing a check on uncertain approximation from theory.

Cameras, lights, and lenses have kept pace with the advance of high-speed photographic technique, but there is still room for advances.

A need exists for an ultra-high-speed film emulsion

to simplify the exposure problem. Similarly, there is a need for standard laboratory development processes for high-speed work. Much of today's high-speed photography is based on experiences in the past on similar projects. The advantage of experience is lost when the film is improperly processed under non-controlled standard conditions. Progress has been made in this field by the Wollensak Optical Company, in cooperation with Ansco and Eastman Kodak. Film prepared by Ansco is sold through Wollensak for users of Fastax cameras. The film cost includes the price of development in a manner similar to the method by which color motion picture film is sold to amateurs. Frequently, however, the delay expended in relaying the film back to the manufacturer cannot be tolerated. A standard field development procedure should be disseminated to all high-speed camera users.

There is a need also for a High-Speed Photographers' Handbook, similar to the Cinematographers' Handbook and Reference Guide,[1] listing high-speed equipment and providing a guide of standard practices and procedures for the working photographer.

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[1] Jackson J. Rose, American Cinematographer Handbook and Reference Guide (Los Angeles: Southland Press, 1950), 299 pp.

High-speed motion picture photography has been described as a means of magnifying time, giving man an insight into the infinitesimally short intervals of eternity, much as the microscope has permitted the magnifying of size. And just as there has been improvement in the microscope leading to the present day electron microscope, with promises of even greater improvement, so must the science and techniques of high-speed photography be improved and advanced.

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